Optimizing 3D Survey Design for Follow-up Programs

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Summary

Contrary to our instincts as scientists, our role is NOT to design seismic surveys that deliver the best images of the subsurface. Rather, as business practitioners, our objective is to design programs that deliver an image that is only adequate for our exploration purposes. We need an image that will lead to drilling success but that minimizes impact on our corporate budget as well as environment and operational constraints.

Conventional statistics such as fold, trace density, offset and azimuth distributions can be calculated for any proposed model. But how these statistical properties interact with the reflection character and/or noise modes that may vary with offset is not conveyed by conventional 3D displays.

Tools are needed that will help us visualize the variation in image quality and desired seismic expression as a function of varying parameters within a specific project area. In this presentation, we will explore the value of data simulation as one such tool. Several examples will demonstrate how data simulation can assist geophysicists in planning subsequent surveys once an initial survey has been recorded in a project area.

Introduction

Designing 3D seismic program parameters is a matter of science and experience. There are many books and articles published on the requirements to properly sample the desired parts of a reflection wavefield using various distributions of sources and receivers on the surface of the earth. However, the methods described focus primarily on theoretical or modelled aspects of desired reflections.

In reality, the wavefield generated by a seismic source and observed in the actual working world contains many elements. In general, the weakest elements are the desired reflection signals. Stronger elements include source-generated coherent noise modes (direct P-waves, direct S-waves, refracted P and S waves, ground roll, air blast and other ground-coupled modes). We should also consider local cultural noise modes such as traffic, cattle, factories, etc.

Basic seismic theory often assumes that noise is random (is unpredictable at any given time), not correlated with any controlled variable in our seismic experiment, and is Gaussian distributed (the noise amplitudes are somewhat uniform in strength and do not contain very high amplitude erratics). However, it is our experience that truly random noise is not very common.

Perhaps the most common and most perplexing problem comes from source-generated, chaotically scattered noise modes. They appear chaotic because of our generally sparse spatial sampling can include scattered surface waves and also chaotically scattered reflections and diffractions from local inhomogeneities in near-surface layers.

These noise modes vary from area to area both in type of noise and in strength and dominance of the noise over signal. Designing surveys to adequately sample such noise modes and optimally recover signal in their presence is far more challenging than creating a simple design to capture ideal reflection signals.

Estimating the type and strength of noise modes and their effect on data quality is an artful guess at best, unless previous seismic has been recorded in a particular project area. This is where experience with many land seismic programs becomes an important input to the design process. However, in a project area where some seismic has already been recorded, we may be able to use the signal and noise characteristics of the legacy data to help optimize the design of our next programs.

Theory and/or Method

So, you have recorded a 3D and are generally happy with the results. Now you are going to move to an adjacent license and record another 3D with the same objectives. Two questions should be pressing on your thoughts. First, could significantly better results be obtained by spending more money and increasing the statistical quality of the 3D? Second, could significant money, time and effort be saved without sacrificing the resulting data quality by decreasing the statistical quality of the 3D?

Or, perhaps, a thorough design process led to the acquisition of a 3D program that yielded surprising results. For reasons that had not been anticipated, the survey totally failed to meet objectives. Could a new 3D program be designed that would provide useful data, and at what cost?

Consider three grid densities in the following figure. The original survey was recorded with 60-meter source and receiver intervals and with receiver line spacing of 420 meters and source line spacing of 480 meters (the center grid). The grid on the left is more dense and somewhat higher cost. The grid on the right is less dense and somewhat lower cost.
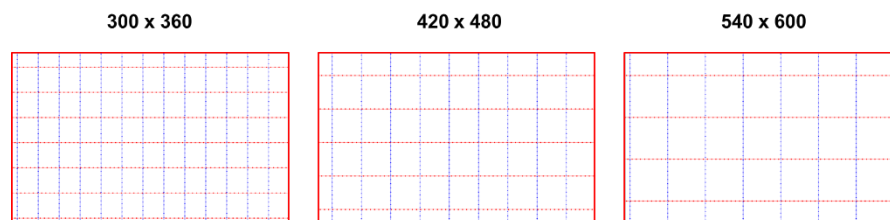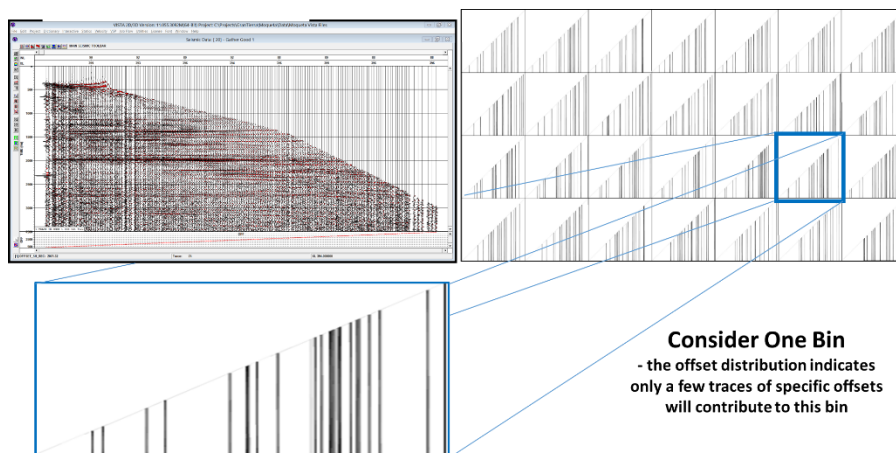

Can the relative merits of these three options be adequately conveyed using the simple fold plots below? How does fold relate to interpretability? Is 75 fold needed, or is 25 fold enough … or the original 40 fold?
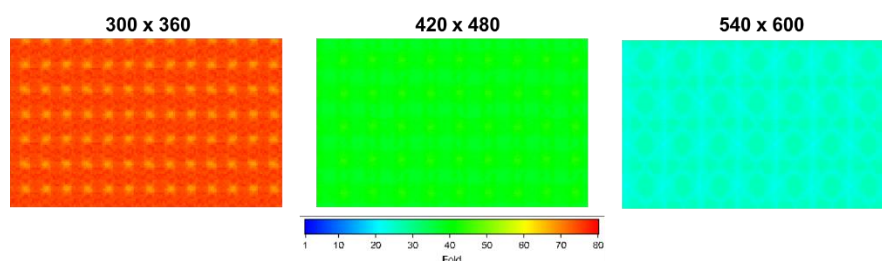
How about offset distributions or largest offset deficiencies? Do these statistics indicate how to optimize the next project?
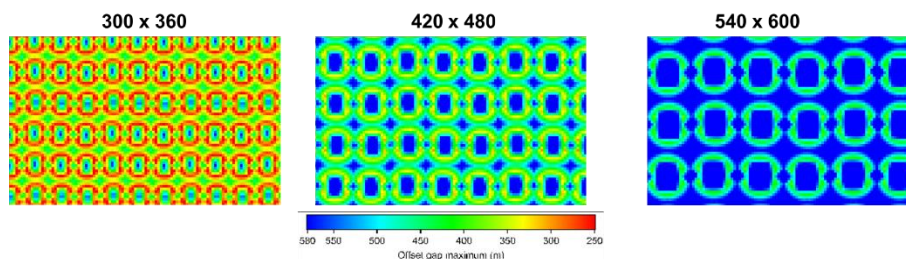
Statistical values based on simple geometric models allow us to rank the various models relative to each other. But they do not illustrate the impact on resulting data quality. Data quality is a function of the model statistics combined with the local signal and noise properties. Simple geometric models provide only the model statistics. Real data is required to assess the signal and noise properties.

Consider One Bin
- the offset distribution indicates only a few traces of specific offsets will contribute to this bin

A typical example of signal and noise variations with offset is provided by a CMP super-gather from existing data (top left in the figures above and below). The geometric 3D model indicates which traces of which offsets will combine in each bin. Then only traces matching the modelled offsets are selected and stacked to form one trace for that bin.

We will use just these traces to form a pseudo-stacked trace for this bin
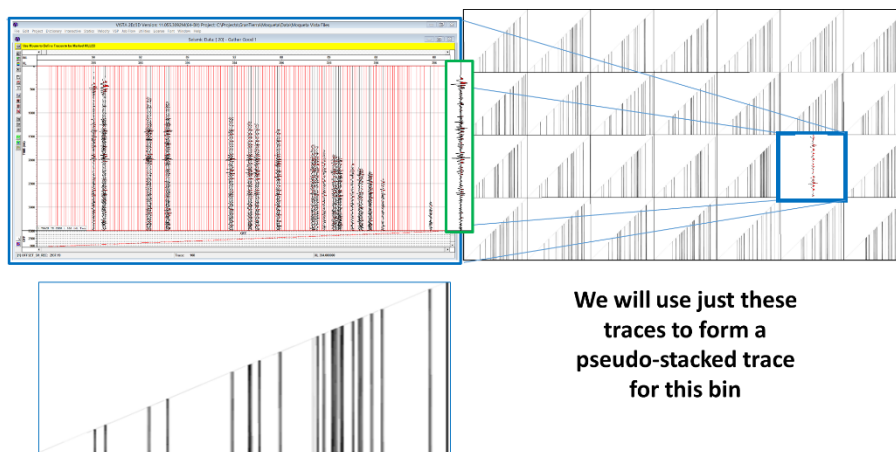
This process is repeated for each bin, but always using the same CMP super-gather for the reference data. In this manner, a complete 3D volume of stacked traces can be simulated. Of course, there will be no geologic changes across the simulated volume because every stacked trace is the sum of subsets of traces from the same CMP gather. However, there will be trace-to-trace differences due to the variation of offset and azimuth distributions from bin to bin.

The following three panels show the data simulations using the three model densities for a specific area. Notice the variations in data quality at different reflectors.
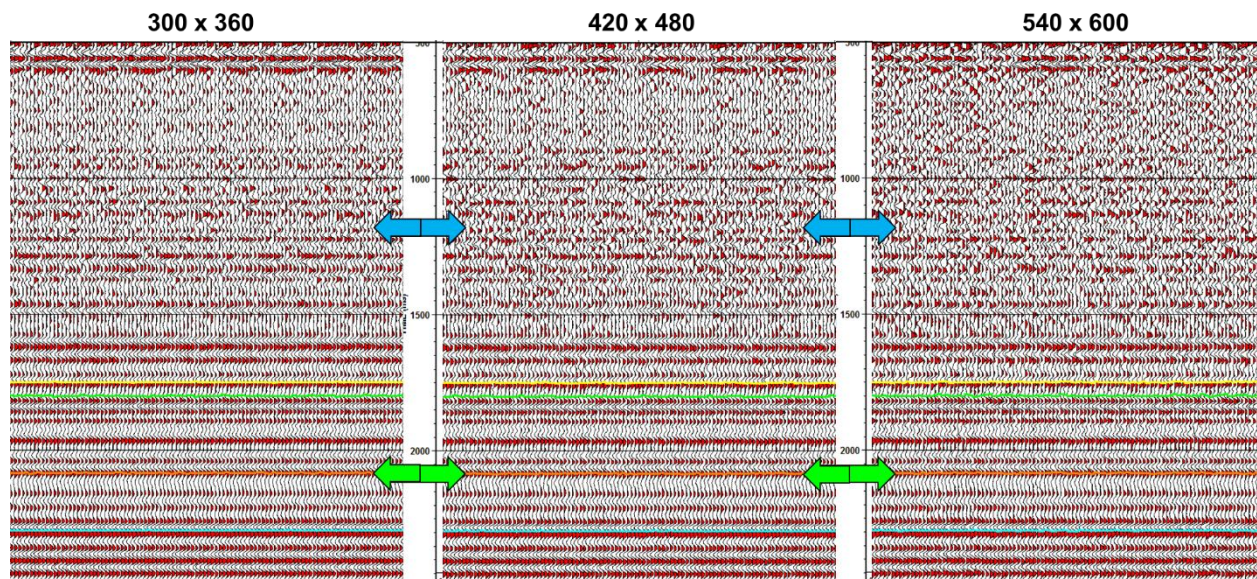
If the prime zone of interest was a gentle structural roll-over at a major reflector such as indicated by the green arrows, then the least dense model is sufficient. The higher dollar cost and environmental disturbance of the two models to the left would not gain significant interpretability for such a prospect.

However, if the prime objective was a stratigraphic trap indicated by subtle changes in wavelet character of the reflectors indicated by the blue arrows, then the higher density model can be justified. This type of display helps qualify model selections and costs to management.

Conclusions

The displays shown in this abstract provide a good qualitative assessment of required 3D density for prospect specific purposes. Simple statistical plots from geometric models do not provide the information needed to refine and optimize seismic surveys in today's competitive environment. It is now necessary to clearly demonstrate value for every expenditure.

As part of the full presentation of this topic, we will also show some tools that have been developed to provide a more quantitative analysis of the data obtained using the simulated data volumes. However, at this time, we think the interpreter's objective view of the simulated data volume will be the most reliable metric for model comparisons.